Quantifying technical skills during open operations using video-based motion analysis

Carly E. Glarner, MD,[a] **Yue-Yung Hu, MD, MPH,**[b] **Chia-Hsiung Chen, MS,**[c] **Robert G. Radwin, PhD,**[d] **Qianqian Zhao, MS,**[e] **Mark W. Craven, PhD,**[f] **Douglas A. Wiegmann, PhD,**[d] **Carla M. Pugh, MD, PhD, FACS,**[a,d] **Matthew J. Carty, MD,**[f] *and* **Caprice C. Greenberg, MD, MPH,**[a] *Madison, WI, and Boston, MA*

Introduction. *Objective quantification of technical operative skills in surgery remains poorly defined, although the delivery of and training in these skills is essential to the profession of surgery. Attempts to measure hand kinematics to quantify operative performance primarily have relied on electromagnetic sensors attached to the surgeon's hand or instrument. We sought to determine whether a similar motion analysis could be performed with a marker-less, video-based review, allowing for a scalable approach to performance evaluation.*
Methods. *We recorded six reduction mammoplasty operations—a plastic surgery procedure in which the attending and resident surgeons operate in parallel. Segments representative of surgical tasks were identified with Multimedia Video Task Analysis software. Video digital processing was used to extract and analyze the spatiotemporal characteristics of hand movement.*
Results. *Attending plastic surgeons appear to use their nondominant hand more than residents when cutting with the scalpel, suggesting more use of countertraction. While suturing, attendings were more ambidextrous, with smaller differences in movement between their dominant and nondominant hands than residents. Attendings also seem to have more conservation of movement when performing instrument tying than residents, as demonstrated by less nondominant hand displacement. These observations were consistent within procedures and between the different attending plastic surgeons evaluated in this fashion.*
Conclusion. *Video motion analysis can be used to provide objective measurement of technical skills without the need for sensors or markers. Such data could be valuable in better understanding the acquisition and degradation of operative skills, providing enhanced feedback to shorten the learning curve. (Surgery 2014;156:729-34.)*

From the Wisconsin Surgical Outcomes Research Program, Department of Surgery,[a] *University of Wisconsin, Madison, WI; Center for Surgery & Public Health, Brigham & Women's Hospital, Department of Surgery,*[b] *Beth Israel Medical Center, Boston, MA; Electrical and Computer Engineering,*[c] *Department of Industrial and Systems Engineering,*[d] *and Department of Biostatistics & Medical Informatics,*[e] *University of Wisconsin, Madison, WI; and Department of Surgery,*[f] *Brigham and Women's Hospital, Boston, MA*

Despite the essential role that technical skill plays in surgery, few objective, evidence-based methods exist to help surgeons assess their technical performance during an operation. The limitations in performance-based metrics have been described both within and outside the discipline of surgery.[1-5] The need for a scalable approach to evaluating individual technical surgical skill objectively remains unmet.

Currently, two types of operative skills assessment are in use: rating scales and motion analysis. Rating scales produce subjectively assigned scores; the use of these tools often requires training and recalibration to achieve test-retest consistency and/or interrater reliability. Motion analysis is an emerging field in skills assessment, aimed at gaining a more objective assessment of technical skill. By tracking metrics such as time, path length, number of movements, velocities, and trajectories, motion analysis addresses the objectivity and reproducibility issues in technical skill assessment. Motion analysis is able to reliably differentiate the level of dexterity

C.E.G. and Y.-Y.H. are co-first authors.

Presented at the Sixth Annual Meeting of the Consortium of ACS-Accredited Education Institutes, March 15–16, 2013, Chicago, IL.

Accepted for publication April 25, 2014.

Reprint requests: Dr Caprice C. Greenberg, MD, MPH, Department of Surgery, University of Wisconsin, 600 Highland Avenue, Madison, WI 53792. E-mail: greenberg@surgery.wisc.edu

0039-6060/$ - see front matter

http://dx.doi.org/10.1016/j.surg.2014.04.054

between expert and novice surgeons performing bench tasks,[6,7] laparoscopic cholecystectomies,[8] and vasectomies and vasectomy reversals.[9] Such data can be used to better understand the acquisition and degradation of operative skill and provide enhanced (ie, specific and precise) feedback to shorten the learning curve.

The aforementioned motion-analysis techniques, however, rely primarily on electromagnetic sensors attached to surgeons' hands or instruments, interrupting the natural flow of the operation and potentially impeding performance. Moreover, the additional equipment in the operative field may pose a risk to patient safety. Finally, the settings in which this analysis can be performed are limited to institutions that have this advanced technology available.

With the increasing availability of recording devices in operating rooms, video-based analysis could fill this gap and provide a generalizable and scalable approach to the assessment of surgical skills. This approach enables the capture of performance without requiring external evaluators to be present in the operating room or surgeons to be encumbered by sensors. We tested a novel tool for marker-less video-based motion analysis that was developed within the field of industrial engineering.[10,11]

Developed at the University of Wisconsin by two of our co-authors (R.G.R. and C.-H.C.),[10] this system uses a conventional digital video. An analyst identifies a selected region of interest (ROI), and the system follows that ROI and calculates the kinematic characteristics, including displacement, velocity, and acceleration. In a study that examined a paced-load transfer task in the laboratory setting, where subjects were asked to transfer weighted bottles from a tray to a turntable at a specified pace, the system has produced similar results to manual frame-by-frame and infrared three-dimensional motion tracking system analyses.[10,11] We performed a feasibility study to determine whether motion analysis using this marker-less, video-based approach could be adapted for the analysis of technical skill performance during open operative procedures.

METHODS

Case and patient selection. In reduction mammoplasties, attending and trainee surgeons often operate simultaneously and in parallel, with one on the left breast and the other on the right breast. In addition, benign breast tissue provides a symmetrical operative field for each of the two surgeons. By contrasting the techniques of the attending and the trainee, the specific components that comprise technical expertise can be identified and studied.

Competent, adult women undergoing bilateral reduction mammoplasty were identified by weekly review of the Pre-Admission Testing Center and Operating Room (OR) schedules. After the surgeon's initial approval to record their cases, patients were sent a recruitment letter from the primary surgeon and the study team. Patients who did not opt out were approached preoperatively for written informed consent using the Partners Institutional Research Board Certificate of Confidentiality consent form (protocol 2011p000655).

Data collection. As part of this feasibility study, we needed to develop the optimal approach to data collection by comparing several ways to capture video images, including in-light camera and head-mounted cameras. Between February and June 2012, 44 potential cases were identified for our study. Permission to record in the OR was obtained from six surgeons. Nineteen of their patients consented to the study. Eleven cases were able to be video-recorded. Nine of these cases had in-light camera view, which was found to provide the only acceptable view for motion analysis. Of these nine cases, six yielded usable video for analysis. Issues that led the remaining videos to be unusable included poor views of the hands, additional surgeons assisting in the operation, and excessive motion artifacts. The six cases included three surgeons with 8–30 years of experience and 3 residents who were in their fourth to sixth year of training. All surgeons and residents were right-hand dominant. Completely deidentified videos were then coded and analyzed.

Analysis. Segments representative of surgical tasks were identified by a surgery resident using Multimedia Video Task Analysis (MVTA) software (http://mvta.engr.wisc.edu/), which allows for coding of video data. The following tasks were coded: cutting with electro-cautery (Bovie; Bovie Medical Corporation, Clearwater, FL), cutting with the scalpel, suturing, and instrument tying. A screenshot of an example of the coding using this software is shown in Fig 1. Using the ROI software developed by the co-investigators,[10] we subsequently analyzed the corresponding coded video segments for their kinematic properties of displacement, velocity, and acceleration. A rectangular ROI was marked manually to identify the focal area at which hand activities are to be tracked, such as a point on the hand or arm. Figure 2 provides a screenshot example of an ROI. A template matching tracking algorithm was implemented to track the ROI motion trajectory over successive video frames. The video data raw location values were low-pass filtered by a

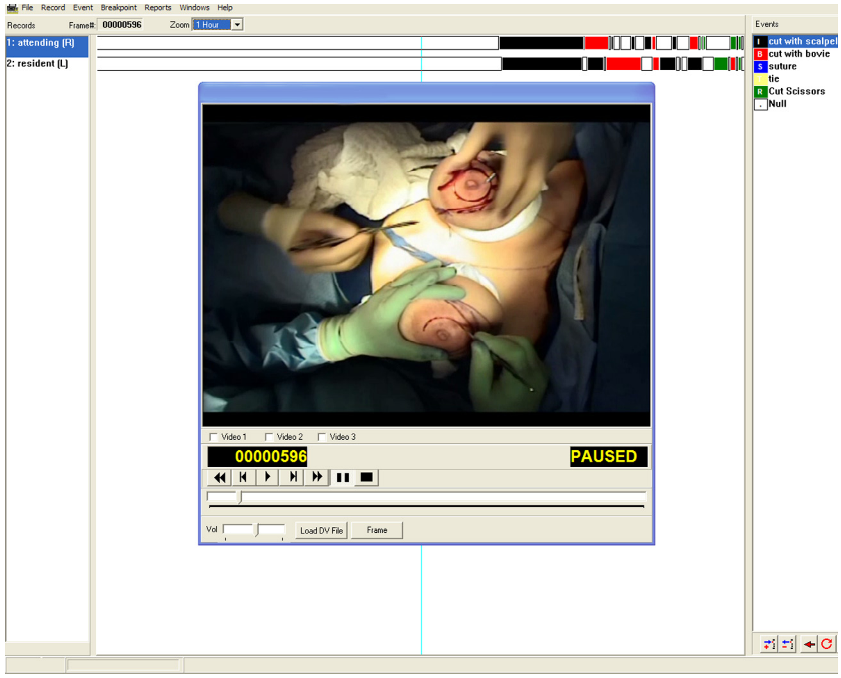

Fig 1. Example of the coding using the MVTA software.

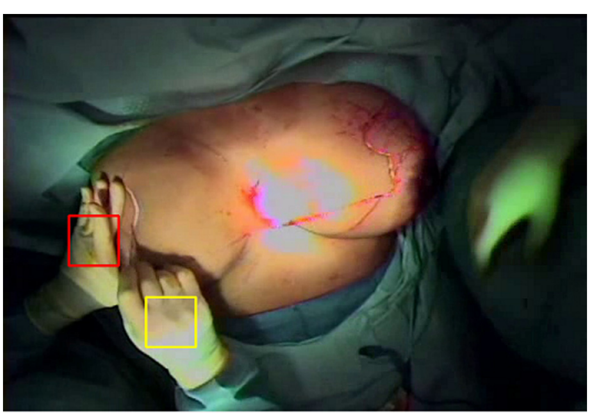

Fig 2. Example of the ROI analysis software, with the right and left hands of the surgeon marked.

Butterworth filter and scaled. The velocity and acceleration at each video frame were calculated by the method of differences.

Exported data on displacement, velocity, and acceleration were analyzed for each task and compared between attending and resident surgeons. Descriptive statistics were generated for attending and resident surgeons' dominant and nondominant hand movements. Because this was a feasibility study, we were not powered to achieve statistical significance. Rather, our aim was to determine whether there were variations in these metrics and to identify patterns that could generate hypotheses to be studied in future work. Analyses were performed using Statistical Analysis Software (SAS; SAS Inc, Cary, NC), MVTA, and the custom marker-less tracking software.[11]

RESULTS

Mean displacement, velocity, and acceleration values for attending and resident surgeons' dominant and nondominant hands are shown for cutting with the Bovie, with the scalpel, suturing and instrument tying (Fig 3, *A–D*).

Attending surgeons appear to use their nondominant hand more than residents when cutting with the scalpel (1,425 mm/s^2 vs 991 mm/s^2), suggesting more use of countertraction in the hand that was not holding the scalpel. Attendings also seem to be more ambidextrous while suturing, with smaller differences in movement between their dominant and nondominant hands, compared with residents, in terms of displacement (11 mm and 10 mm vs 10 mm and 6 mm), velocity (276 mm/s and 248 mm/s vs 241 mm/s and 167 mm/s), and acceleration (3,345 mm/s^2 and 3,246 mm/s^2 vs 2,867 mm/s^2 and 2,010 mm/s^2). Finally, analysis of attendings suggests more conservation of movement when performing instrument tying, as demonstrated by less nondominant hand displacement (14 mm vs

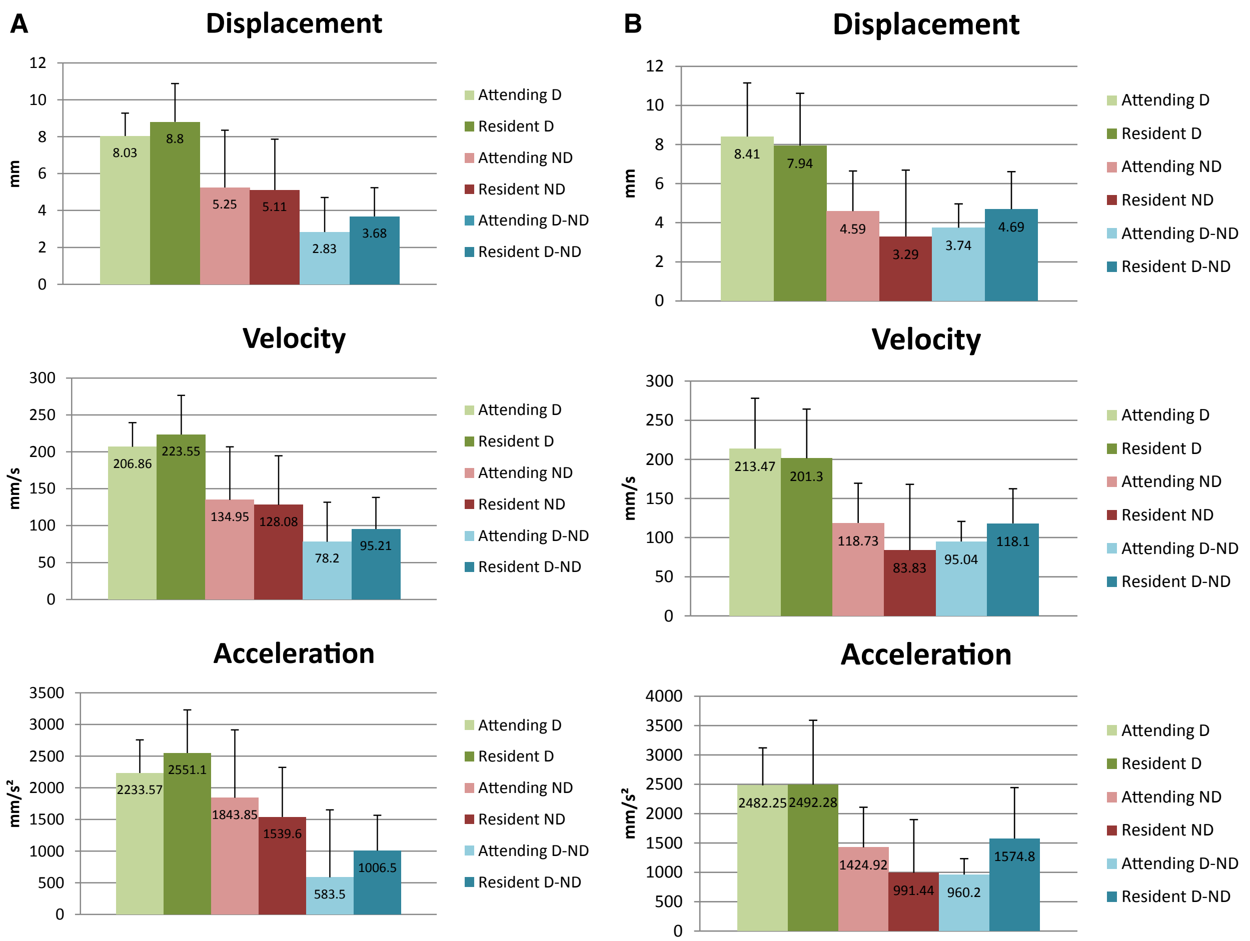

Fig 3. Analysis of dominant hand (D), nondominant hand (ND), and difference between dominant and non-dominant hand (D-ND) displacement, velocity, and acceleration. (*A*) Cutting with Bovie. (*B*) Cutting with scalpel. (*C*) Suturing. (*D*) Instrument tying. Values are mean ± SD, as shown by the error bars.

23 mm), velocity (379 mm/s vs 576 mm/s), and acceleration (5,273 mm/s^2 vs 3,877 mm/s^2).

DISCUSSION

Although central to a surgeon's profession, technical skill remains a poorly defined construct. Previous studies on motion analysis in open surgical tasks have primarily focused on the time to complete a task, number of movements, and total path length[6,9,12-14]; however, using a motion-video analysis tool, we were able to deconstruct larger tasks into subcomponents that compose those tasks, including the movements involved in tying and suturing. This study suggests that surgeons may use their nondominant hand more to assist themselves than do residents, provide themselves with more countertraction when cutting with the Bovie and scalpel, and actively use the forceps to assist themselves when suturing. When performing instrument tying, surgeons appear to have more conservation of movement in their nondominant hands than residents, suggesting more efficient motion.

This study was performed to assess feasibility. Results come from a single institution, with a limited number of participants. During our recorded cases, the attending surgeons operated on the right, whereas the resident operated on the left, as is typical during this procedure. Additionally, the surgeon supervised the resident's performance. It is possible that this positioning and the fact that they were teaching cases may have affected the results. Because the camera was housed in an operative light that was positioned by the surgical team, and because our system is currently only able to capture two-dimensional data, the different angles of the cameras may prevent direct comparisons between cases. We chose the reduction mammoplasty procedure because this operation minimizes variation in

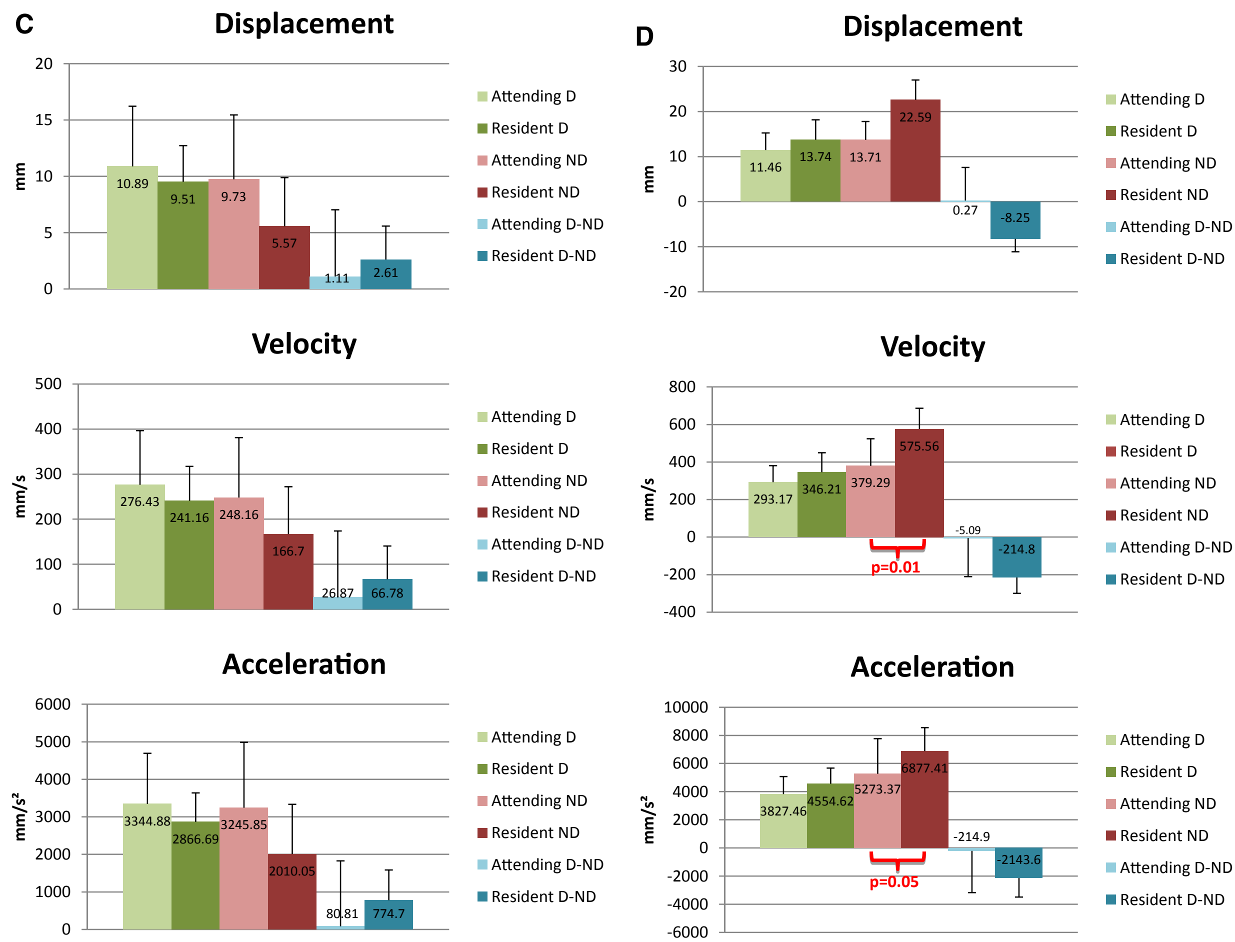

Fig 3. (*continued*)

operative context. Because this was an exploratory study, we did not attempt to conduct a formal statistical analysis. Now that we have studied the feasibility of this method of analysis, we plan to address these limitations by analyzing technical performance across a larger range of surgical abilities and different operations within the OR and in simulation settings.

Video motion analysis holds great promise as a feasible way to collect data on technical performance and provide an objective measurement of technical skill without the need for the surgeons to wear markers or other types of sensors. Previous studies on motion analysis in surgery have focused primarily on laparoscopic cases performed in simulated settings.[15] The few studies that have been performed on open procedures have necessitated the surgeons to wear sensors on their hands or instruments.[6,9,12-14] In this study, we were able to extract data on surgeons' hand movements from open operative procedures performed in the operating room directly from digital video without the need for any physical sensors. This noninvasive approach to data capture markedly enhances the generalizability and scalability of technical skills assessment in the operating room. Coupled with the increased availability of recording devices, implementation of this assessment modality should be feasible in a wide variety of settings.

REFERENCES

1. Bass BL, Polk HC, Jones RS, et al. Surgical privileging and credentialing: a report of a discussion and study group of the American Surgical Association. J Am Coll Surg 2009;209:396-404.
2. Dent TL. Training and privileging for new procedures. Surg Clin North Am 1996;76:615-21.
3. Sachdeva AK. Acquiring skills in new procedures and technology: the challenge and the opportunity. Arch Surg 2005;140:387-9.
4. Sachdeva AK, Russell TR. Safe introduction of new procedures and emerging technologies in surgery: education,

credentialing, and privileging. Surg Clin North Am 2007;87:853-66; vi-vii.
5. American College of Surgeons. Statements on Emerging Surgical Technologies and the Evaluation of Credentials. Bull Am Coll Surg 1994;79:40-1.
6. Saleh GM, Voyatzis G, Hance J, Ratnasothy J, Darzi A. Evaluating surgical dexterity during corneal suturing. Arch Ophthalmol 2006;124:1263-6.
7. Obstein KL, Patil VD, Jayender J, et al. Evaluation of colonoscopy technical skill levels by use of an objective kinematic-based system. Gastrointest Endosc 2011;73:315-21.
8. Dosis A, Aggarwal R, Bello F, et al. Synchronized video and motion analysis for the assessment of procedures in the operating theater. Arch Surg 2005;140:293-9.
9. Grober ED, Roberts M, Shin EJ, Mahdi M, Bacal V. Intraoperative assessment of technical skills on live patients using economy of hand motion: establishing learning curves of surgical competence. Am J Surg 2010;199:81-5.
10. Radwin RG. Automated video exposure assessment of repetitive motion. Hum Factors 2011;55:995-6.
11. Chen CH, Hu YH, Yen TY, Radwin RG. Automated video exposure assessment of repetitive hand activity level for a load transfer task. Hum Factors 2013;55:298-308.
12. Bann SD, Khan MS, Darzi AW. Measurement of surgical dexterity using motion analysis of simple bench tasks. World J Surg 2003;27:390-4.
13. Datta V, Mackay S, Mandalia M, Darzi A. The use of electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory-based model. J Am Coll Surg 2001;193:479-85.
14. Datta V, Chang A, Mackay S, Darzi A. The relationship between motion analysis and surgical technical assessments. Am J Surg 2002;184:70-3.
15. van Hove PD, Tuijthof GJ, Verdaasdonk EG, Stassen LP, Dankelman J. Objective assessment of technical surgical skills. Br J Surg 2010;97:972-87.